

# *Abbreviations, Symbols and Units Used in Text*

## **Abbreviations**

a.c.	alternating current
AFC	alkaline fuel cell
ATP	adenosine 5'-triphosphate
BEV	battery electric vehicle
CB	conduction band
CBM	coal-bed methane
CCGT	combined-cycle gas turbine
CCS	carbon capture and storage
CFC	chlorofluorocarbon
CHP	combined heat and power
CNG	compressed natural gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CUTE	Clean Urban Transport for Europe
DAFC	direct alcohol fuel cell
DBFC	direct borohydride fuel cell
d.c.	direct current
DCFC	direct carbon fuel cell
DMFC	direct methanol fuel cell
DOE	Department of Energy (USA)
DSSC	dye-sensitized solar cell
e	(subscript) electrical
ECBM	enhanced coal-bed methane
ECTOS	Ecological City Transport System
EOR	enhanced oil recovery
EU	European Union
EV	electric vehicle

FC	fuel cell
FCV	fuel cell vehicle
GDP	gross domestic product
GHG	greenhouse gas
GTL	gas-to-liquids
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HEV	hybrid electric vehicle
HFC	hydrofluorocarbon
HHV	higher heating value
HTGCR	high-temperature gas-cooled reactor
IAHE	International Association for Hydrogen Energy
ICE	internal combustion engine
ICEV	internal-combustion-engined vehicle
IEA	International Energy Agency
IGCC	integrated gasification combined-cycle
IPCC	Inter-governmental Panel on Climate Change
IPHE	International Partnership for the Hydrogen Economy
IT	information technology
LH <sub>2</sub>	liquid hydrogen
LHV	lower heating value
LNG	liquefied natural gas
LPG	liquid petroleum gas
M <sub>ox</sub>	redox mediator in oxidized state
M <sub>red</sub>	redox mediator in reduced state
MCFC	molten carbonate fuel cell
MEA	membrane–electrode assembly
MEMS	microelectromechanical systems
MIT	Massachusetts Institute of Technology
MOC	Meridional overturning cycle
MOF	metal–organic framework
MPV	multi-purpose vehicle
NADP	nicotinamide adenine dinucleotide phosphate
NASA	National Aeronautics and Space Administration (USA)
NGL	natural gas liquids
NO <sub>x</sub>	nitrogen oxides
NTP	normal temperature (273.15 K) and pressure (101.325 kPa)
OECD	Organisation for Economic Co-operation and Development
OPV	organic (polymer-based) photovoltaic

PAFC	phosphoric acid fuel cell
PEC	photo-electrochemical
PEM	proton-exchange membrane
PEMFC	proton-exchange membrane fuel cell
PF	pulverized fuel
PFC	perfluorocarbons
PSA	pressure swing adsorption
PTFE	polytetrafluoroethylene
PV	photovoltaic
RAPS	remote-area power supply
SHE	standard hydrogen electrode
SI	Système International
SO <sub>x</sub>	sulfur oxides
SOFC	solid oxide fuel cell
SPE	solid polymer electrolyte
SPEFC	solid polymer electrolyte fuel cell (same as PEMFC)
STEP	Sustainable Transport Energy Project
STP	standard temperature (298.15 K) and pressure (101.325 kPa)
SUV	sports utility vehicle
Syngas	synthesis gas
th	(subscript) thermal
UAV	unmanned aerial vehicle
USCAR	United States Council for Automotive Research
UTC	United Technologies Corporation
VB	valence band
WGS	water-gas shift reaction
YSZ	yttria-stabilized zirconia

## Symbols and Units

Sub-units			Multiple units		
d	deci	10 <sup>-1</sup>	k	kilo	10 <sup>3</sup>
c	centi	10 <sup>-2</sup>	M	mega	10 <sup>6</sup>
m	milli	10 <sup>-3</sup>	G	giga	10 <sup>9</sup>
μ	micro	10 <sup>-6</sup>	T	tera	10 <sup>12</sup>
n	nano	10 <sup>-9</sup>	P	peta	10 <sup>15</sup>

atm	atmosphere (= 101.325 kPa)
A	ampere
Ah	ampere-hour
b	barrel of oil
bar	unit of pressure (= 100 kPa)
bhp	brake horsepower (= 745.7 W)
<i>c</i>	speed of light in vacuum (= $2.998 \times 10^8 \text{ m s}^{-1}$ )
<i>C</i>	coulomb (= 1A s)
C	carbon
cal	calorie (= 4.184 J)
cm	centimetre
°C	degree Celsius
$e^-$	electron
$\eta$	electrode overpotential (V)
$\eta_+$	overpotential at a positive electrode (V)
$\eta_-$	overpotential at a negative electrode (V)
eV	electron volt (= $1.602 \times 10^{-19} \text{ J}$ )
<i>E</i>	electrode potential (V)
$E^\circ$	standard electrode potential (V)
<i>E</i>	energy (expressed in eV)
$E_{\text{CB,b}}$	energy at bottom of conduction band (eV)
$E_{\text{F}}$	Fermi level in a semiconductor (eV)
$E_{\text{g}}$	band gap energy (eV)
$E_{\text{VB,t}}$	energy at top of valence band (V)
ft	foot (linear measurement = 305 mm)
F	Faraday constant (= 96 458 C mol <sup>-1</sup> )
g	gram
<i>G</i>	Gibbs free energy (J mol <sup>-1</sup> )
$\Delta G$	change in Gibbs free energy (J mol <sup>-1</sup> )
$\Delta G^\circ$	standard change in free energy (J mol <sup>-1</sup> )
<i>h</i>	Planck's constant ( $6.626 \times 10^{-34} \text{ J s}$ )
<i>hν</i>	energy of a photon
h	hour
$h^+$	electron hole in valence band
<i>H</i>	enthalpy (J mol <sup>-1</sup> )
$\Delta H$	change in enthalpy (J mol <sup>-1</sup> )
$\Delta H_{\text{f}}^\circ$	standard heat (enthalpy) of formation (J mol <sup>-1</sup> )
in	inch (linear measurement = 2.54 cm)
<i>I</i>	current

$IR'_e$	resistive losses in electrolyte (V)
$IR'_t$	total resistive losses in electrodes (V)
J	joule (= 1 W s)
K	kelvin (a measure of absolute temperature)
$\lambda$	wavelength of electromagnetic radiation
L	litre
m	metre
mol	mole, <i>i.e.</i> , mass of $6.022 \times 10^{23}$ elementary units (atoms, molecules, <i>etc.</i> ) of a substance
Mtoe	million tonnes of oil equivalent
$\nu$	frequency of electromagnetic radiation
$n$	number of units (electrons, atoms, molecules) involved in a chemical or electrochemical reaction
N	newton (unit of force = $1 \text{ kg m s}^{-2}$ )
$\text{N-m}^3$	normal cubic metre of gas ( <i>i.e.</i> , that measured at NTP)
$\Omega$	ohm
ppmv	parts per million by volume
psi	pounds per square inch (1 psi $\approx$ 6.895 kPa)
$P$	pressure
Pa	pascal (1 Pa = $1 \text{ N m}^{-2} = 9.869 \times 10^{-6}$ atm)
$R'$	resistance ( $\Omega$ )
$R$	gas constant (= $8.1345 \text{ J K}^{-1} \text{ mol}^{-1}$ )
s	second
$S$	entropy ( $\text{J K}^{-1} \text{ mol}^{-1}$ )
$\Delta S$	change in entropy ( $\text{J K}^{-1} \text{ mol}^{-1}$ )
t	tonne
$T$	temperature
$T_c$	critical temperature
vol.%	volume percent
$V^\circ$	reversible cell voltage (V) under standard conditions of temperature (298.15 K) and pressure (101.325 kPa); also known as the standard cell voltage
$V_p$	practical cell voltage (V)

$V_r$	reversible cell voltage (V)
V	volt
W	watt
$W_e$	watt, electrical power
$W_p$	peak watt (for solar cells)
$W_{th}$	watt, thermal power
Wh	watt-hour
wt. %	weight percent
$x$	variable in stoichiometry